Automatic Pedestrian Network Generation

Miquel Ginard Ballester[1, 2], Maurici Ruiz Pérez[2] and John Stuiver[3]

[1]Geographic Information Management and Applications (GIMA) Master Science, The Netherlands
[2] GIS and Remote Sensing Service (SSIGT), Balearic Islands University, Spain
[3] Laboratory of Geo-Information Science and Remote Sensing, Wageningen University, The Netherlands

ABSTRACT

To model pedestrians' mobility in GIS, the traditional approach used to model transport networks based upon streets centre-lines must be improved. Nowadays, a new level of network detail is needed, representing accurately the real objects used for pedestrians (and their attributes) instead of the ones used for vehicles. This leads to a world of possibilities and applications barely explored.

This paper analyses the existing need for pedestrian networks and the scarcity of its availability. The effects of using street networks for studying and/or analyzing pedestrians' mobility, as it is commonly done to date, are also discussed. To solve this problem, a method to automatically derive pedestrian networks based upon existing geo-data is proposed. The inputs (streets and building blocks) and outputs of the method are presented and critically analyzed.

INTRODUCTION

Since the beginning of modern geographic information techniques, transport networks have been mainly created based upon the point of view of vehicle drivers. As an example, until today the most common transport network used in most accessibility and connectivity studies is the street network (Frank, L. and Engelke, P., 2001; Handy, S. et al., 2002). This kind of network is generally modelled in GIS using a vector approach. This approach consists of a graph containing edges (street centre-lines) and nodes (intersections), which may be overlapping, represented in an Euclidian plane; together with a set of associated attributes, such as unique identifiers, road classification, street name, maximum speed, etc. (Scheider, S. and Schulz, D., 2007).

The above-mentioned methodology is highly realistic when modelling transport networks for vehicles; or even for pedestrian networks when talking about walkway-streets. Many other types of transport network also exist (like railway, bus, cycling networks, etc.) and they mostly use a similar modelling approach to the one described above. All these common transport network typologies are based upon the point of view of vehicles, while networks including non-motorist travel routes are rarely available or collected (Chin G. K. V. et al., 2008).

As in most modern cities, vehicles have taken a central role to satisfy the mobility needs of its inhabitants, whereas pedestrians have been marginalized and come in second place. Nowadays, pedestrians are generally restricted to walk on pavements. Moreover, they need to take care not to be knocked down by a vehicle when crossing each street. Therefore, different spatial elements are used for pedestrians than for vehicles due to their differing routes.

On the other hand, unlike vehicle networks, pedestrian networks can incorporate both informal and formal paths, including pavements, signalized and un-signalized pedestrian crossings, walkways, pedestrian bridges and parks paths (Chin, G. K. V. et al., 2008). Therefore, pedestrian networks and the street networks are considerably different. For this reason, the usage of street networks to study pedestrian movements, as it is commonly done to date, is questionable in several ways, as illustrated in the table below:

SPATIAL
Usually several metres separate the street centre-line from the walkable area (pavements)
By using street networks one assumes that pedestrians walk on the correct side of the street
Street morphology affects pedestrian movements (Mohareb, N. I., 2009)

TEMPORAL / ROUTING
Accuracy is lost when calculating routes derived from the un-accurate spatial representation of the pedestrian network with the traditional approach
Cross each street needs from an extra travelling time/impedance. That is because pedestrians first need to either wait for traffic lights or make sure vehicles are not passing before they can safely cross the street
Several authors have already proved that important differences exist between analysis performed with pedestrian networks and with street networks, as shown in the figure below.

Figure 1: Differences in accessibility measures between street and pedestrian networks per neighbourhood type in Perth, Australia. Source: Chin, G. K. V. et al., 2008

ATTRIBUTES
Different attributes can be considered for pedestrian networks rather than for vehicle networks, such as: width of pavement, pavement type, slopes; pedestrian crossing ramps, traffic signs, traffic of the street crossed; universal mobility needs (Ruiz, M., et al., 2008; Yari, I. and Igi, S., 2007; Ruiz, M., et al., 2010), walkability measures (Clifton, K.. J. et al., 2007, Cerin, E. et al., 2007; Smith, K. R., et al., 2008; Goetzke, F. and Andrade, P. M., 2010), etc. These attributes will influence or condition the pedestrian network accessibility, travelling impedances and/or attraction/repulsion factors
Attributes and its information will limit and/or condition the possible pedestrian network-based applications and analysis

Table 1: Accuracy differences between street networks and pedestrian networks

OBJECTIVES

The main objective of this research is to develop a methodology to automatically generate pedestrian networks. This main objective is divided into five different sub-objectives. They are: generate pedestrian networks based upon existing and easily accessible geo-datasets; the methodology should be applicable to the whole of Spain with the possibility of applying it to other areas/countries; the methodology should be easily interchangeable between different computers/users; final users effort should be as minimized as possible; and the methodology should be as effective and efficient as possible

PROPOSED METHODOLOGY

As explained before, the traditional approach used to model street networks usually consists of lines (arcs) to represent the street centre-line (displayed in black in figure 2), and points (nodes) to

represent its intersections or crossings (displayed in green in figure 2) (Scheider, S. and Schulz, D., 2007). As explained above, this traditional method is shown to be inappropriate for modelling pedestrian movements.

Pedestrian Network Abstraction

The added value of this research is to automatically model transport networks using a barely developed extraction of the reality (Kim, Y. K. et al., 2007) based upon the real elements used by pedestrians. This modelling approach proposes to abstract pedestrian networks into lines (arcs) to represent the pavements from each side of the street (in blue in figure 2), and lines (arcs) at each intersection to represent pedestrian crossings (with or without traffic sign) connecting the different blocks' pavements (in purple in figure 2)

REALITY (ORTOFOTO) ⟹ TRADITIONAL APPROACH ⟹ PROPOSED APPROACH
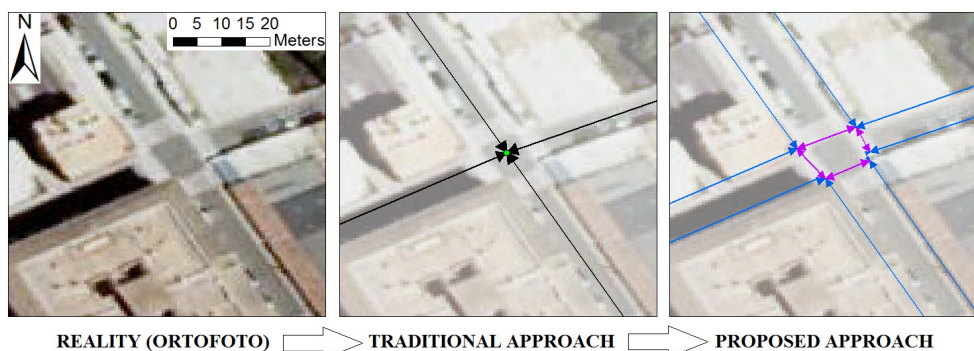
Figure 2: Pedestrian Network modelling approach.

Information Sources

In order to automatically generate pedestrian networks, some input geo-datasets are needed. These are:

1. A 'traditional' street-segment network (arcs & nodes). It is important to note that lines representing street segments are needed and not lines representing the whole street
2. Polygons representing urban / building blocks
3. Polygon(s) representing the area where the network is to be generated (like a municipalities map)

As stated in the objectives, this methodology should be applicable at least to the whole of Spain and, with some modifications, to other areas or countries. In order to facilitate and promote an open usage and diffusion of the methodology, research for possible freely-available geo-datasets meeting the above-mentioned requirements was performed. Different sources offering one or more of the above-mentioned geo-datasets were found, such as:

-   IGN: the Spanish National Geographic Institute has recently adopted an open data access policy in concordance with the INSPIRE Directive (IGN, 2010). Nowadays, the IGN offers several datasets which can be freely downloaded from its SDI via the so-called 'download centre'[1].
-   Open Street Map: the Open Street Map is '*a freely edited map from the whole World that allow users see, edit and use geographic information in a collaborative way from everywhere in the world*' (Open Street Map, 2010). Despite this initiative is offering one of the most up-to-date street maps with global coverage, the attributes and spatial accuracy and feasibility are, at best, questionable. As an example, the street centre-line in many cases falls within blocks.
-   Other non freely-available sources also offer the above-mentioned geo-datasets within their products (like the Spanish Cadastre or private organizations) but they were not considered within this research.

Finally, Cartociudad data, freely available in the IGN, was chosen to be used within this research. Cartociudad project is '*the result of data integration and harmonization from different public*

---

[1] See: http://centrodedescargas.cnig.es/CentroDescargas/index.jsp (December, 2010)

organizations (Cadastre [DGC], National Statistic Institute [INE], Mail and Telegraph State Society [Correos] and the IGN) which has become a geographic national information system containing: continuous street network, and parcel (blocks), censual and postal information' (Cartociudad, 2010).

One of the main reasons for choosing Cartociudad data is its status as an official and highly feasible source. Another important reason that motivates choice for this source is its offer of all the three required geo-datasets to generate the pedestrian network. This represents an important comparative advantage compared with the usage of mixed-source data, where spatial accuracy and/or attributes inconsistencies between datasets can appear.

Technology

To create a tool to automatically generate pedestrian networks ArcGIS 9.3 Desktop (ArcInfo) software has been used. This GIS software offers a powerful tool (the model builder) to develop new and complex tools that can be easily modified and interchanged. Once developed, the ESRI model-based tools can be exported as (java or python) scripts / algorithms to be used in other compatible GIS software.

The proposed method has been created in a three-step model-based tool to automatically generate pedestrian networks. The motivation for creating the tool in different steps may look strange at first, but it comes from several factors which are discussed in the next sections.

Step 1: Project inputs & Geo-database creation

The first model-based tool consists of the creation of a folder and a Geo-database (GDB) within it where all inputs, outputs and intermediate results will be stored. This choice is motivated because ArcGIS is not able to use alias name for data locations. Therefore, in order to ensure the interoperability of the tool on different computers and/or software, the folder is automatically created in the location 'C:\Program Files\'. This location used to be available in most Windows environments.

On the other hand, this first tool defines the same Projected Coordinate System (with units expressed in metres) for all input geo-datasets (if needed) and for the GDB (as illustrated in figure 3). This process will, on the one hand, avoid possible geometry problems with geo-processes and, on the other hand, units expressed in metres will facilitate users' usage or future modification(s) of the model.
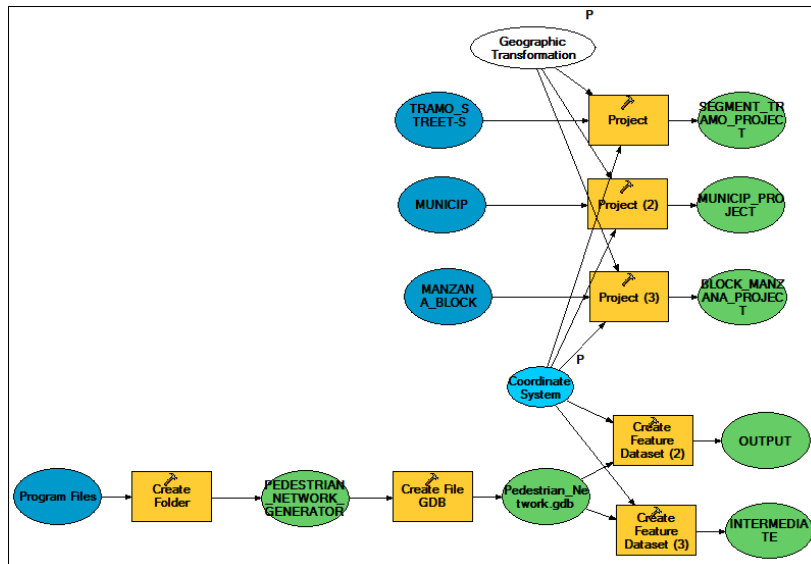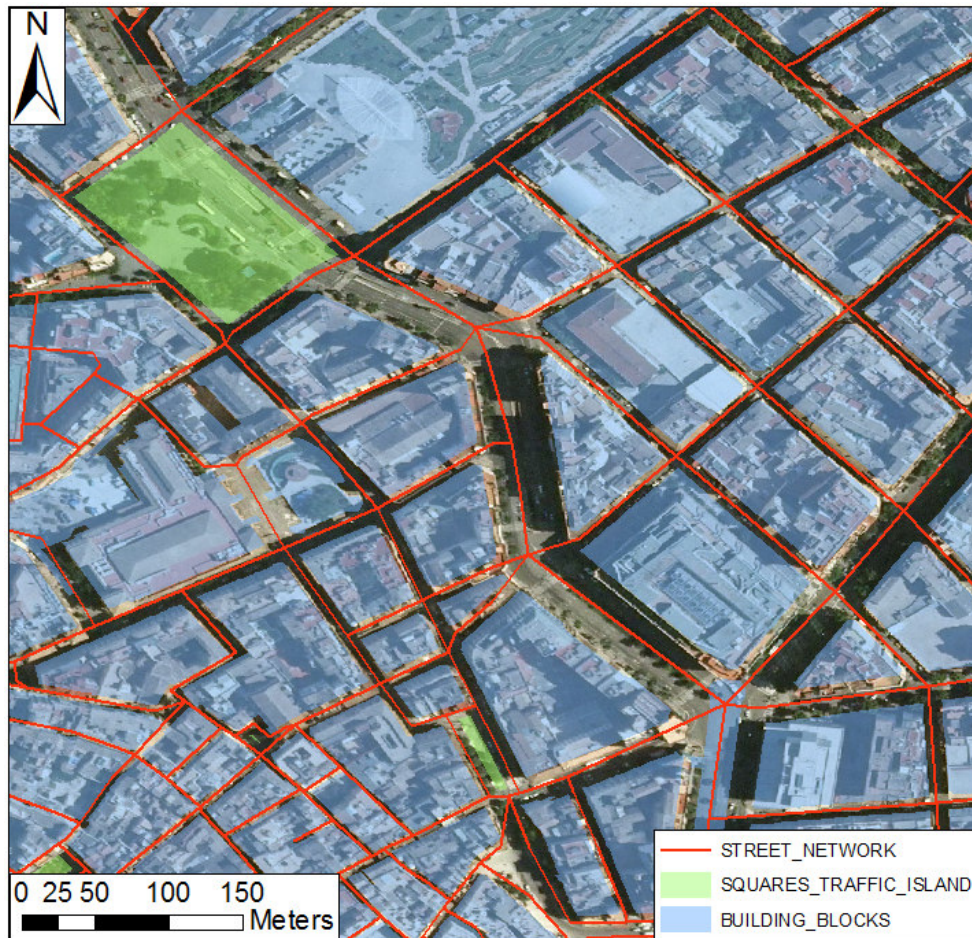

Figure 3: first-step model-based tool.

4

Figure 4: inputs and intermediate result in Palma de Mallorca, Spain Square area

Step 2: Generate the Pedestrian Network

The second tool consists out of a combination of 127 geo-processes that generate the pedestrian network for the selected area/municipality. The whole complexity of this tool cannot be explained in a short paper, but its main steps and rectification/sensibility parameters are described as clearly and briefly as possible in the next paragraphs.

Before starting, it must be recognised that in this case study most squares, parks and/or traffic islands were not present in the input (polygon) blocks geo-datasets. As most of these objects are considered to be an important part of the pedestrian network, a process to derive them has been implemented within the tool (see figure 4). This process may not be needed when using different input datasets. In such a case, the model needs to be manually rectified by the user.

The first processes consist of reducing / clipping the input datasets to the selected area. In this case study, the area of interest is selected from the municipality map. This way, one/some/all municipality(s) from the input can be selected. It is recommended not to apply this tool to large areas due to excessive computing time.

Next, the model calculates the average distance from each street segment to 45cm away from its bordering blocks. The 45 centimetre buffers are applied because, on the one hand, pedestrians walk at a certain distance from block/building walls and, on the other hand, because this distance is exactly half of the minimum pavement width (90cm) set by the Balearic and Spanish Laws on Universal Mobility and Architectonical Barrier Suppression (IMSERSO, 2004; Balearic Islands Government, 2003).

5

Then, through a complex method a continuous network of pavements, pedestrian crossings and walk-paths is generated. By using the above-calculated average street segment width, pavements are generated. Walk-paths are extracted from the (parts of) input street lines passing through parks, squares and/or traffic islands. However, the pedestrian crossing generation method cannot be explained shortly and without entering in lots of technical details.

On the other hand, average pedestrian crossing distance from block corners tends to vary in different neighbourhoods. For this reason, a method which allows users to adjust this parameter to the study area characteristics has been implemented within the tool.
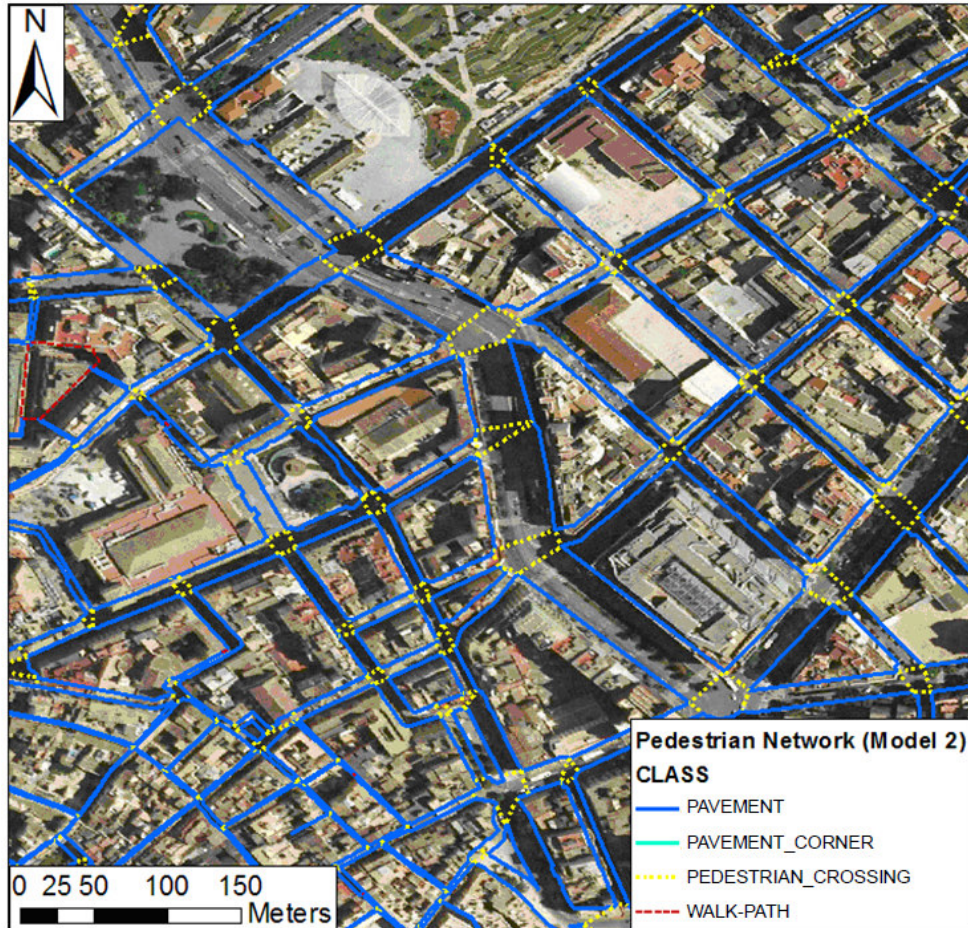
Figure 5: second step tool output in Palma de Mallorca, Spain Square area.

Another method to avoid small digitalization errors from the input (when street centre-line and block polygons overlap) has also been developed. The pre-defined tolerance to remove small errors is set to 5m, but it can be modified by the user. This means that lines overlapping the polygon by more than 5 metres are assumed to represent a real pass (mostly at different level) through the block. Moreover, a simplification method to avoid too many pedestrian crossings (< 15m from each other) has been implemented within the tool as well.

Finally, an attribute field ('CLASS') differentiating between pedestrian crossings, square/park-paths, pavements and corner pavements is calculated. This whole process results in an accurate pedestrian network geo-dataset, as it can be appreciated in the map (figure 5).

6

**Step 3: Create Network Attributes**

The process to create network atributtes is performed separately because the pedestrian network attributes will vary depending on the inputs used to generate it. The first part of the model consists of deleting unnecessary fields resulting from intermediate processes. Next, in a new field ('PEDEST_ID') a unique identified is assigned to each network element.

Then, the tool associates attributes from the used inputs to the output pedestrian network, recognizing the input object used to derive each output element. Street segment identifiers are assigned to all network elements, while building block identifiers are associated only to pavements.

Finally, a standardized set of fields, including (most of) the attributes from the elements represented by the pedestrian network (under Clifton, K. J. et al., 2007, and Perez Ruiz, M., et al., 2008), are added.

RESULTS AND DISCUSSION

The result of the proposed methodology is a tool applicable to the whole of Spain and, with some modifications, to other counties. Its output is a GDB containing the projected input geo-datasets, the output pedestrian network for the selected area together with other intermediate results.
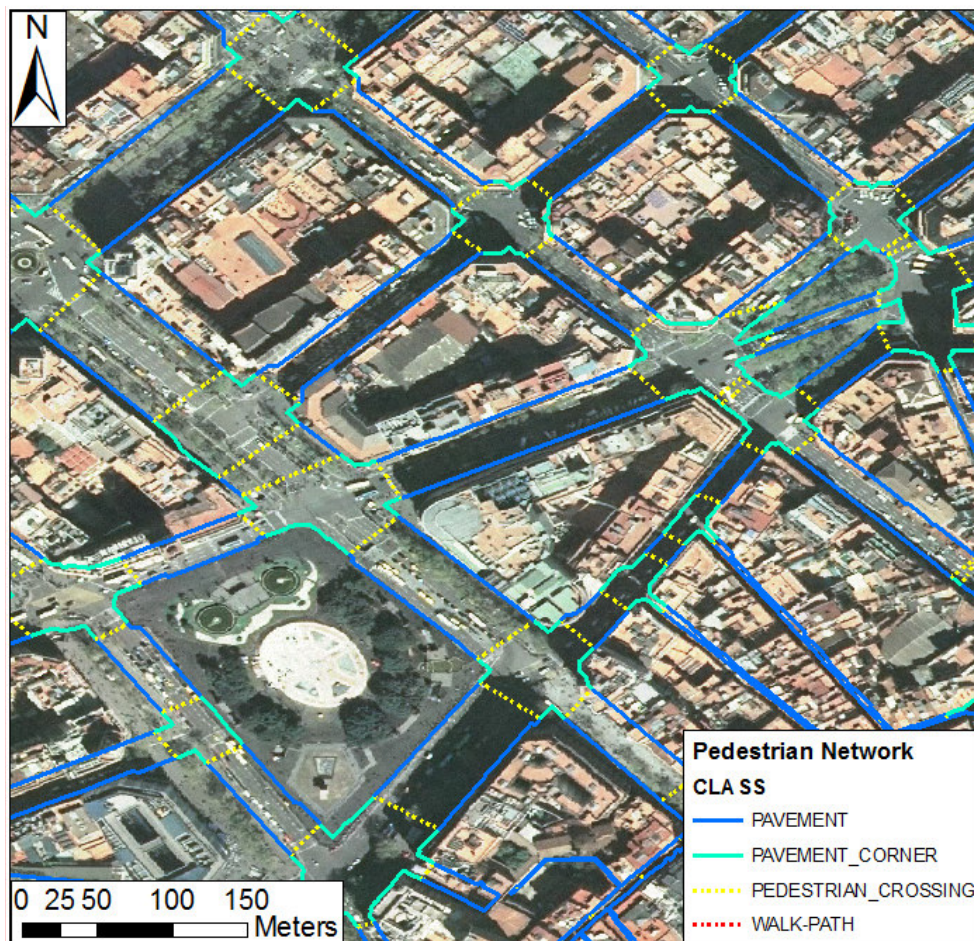
Figure 6: Output pedestrian network in Barcelona, Catalonia Square area.

The model output represents with high reliability a continuous network of pavements, pedestrian crossings and walk-paths, as illustrated in the figures 5, 6 and 7.

7

In order to facilitate final users' usage, all model-based tools can be used with a 'standard' ArcGIS tool interface by simply double clicking it. Then, as explained before, some parameters need to be adjusted by the user. These parameters differ in each of the three models. For this reason, a description of each tool and their parameters is provided in order to facilitate users' usage.

As it can be appreciated from the map above (figure 6), the output pedestrian network adapts almost perfectly to both regular block areas with wide streets (Eixample District, on the upper left side) and to irregular block areas with narrow streets (Old City, on the lower right side). In this example figure, the average crosswalk distance from blocks corner has been set to a high value (10 meters) according to the Eixample neighbourhood characteristics resulting in a most suitable pedestrian network for this area.

In the figure below, from Utrecht city centre, the output pedestrian network from a modified version to run under the Dutch Cadastre Top10 datasets[2] is shown. Nonetheless, like in Spain, the modified version also runs for the all tested areas in Netherlands. When properly adjusted, the tool does not fail even when input data inconsistencies exist, as they are mostly automatically repaired. This fact proves the interoperability and efficiency of the tool. However, to properly apply the tools, area specific knowledge is required to correctly set their parameters.

Figure 7: Output pedestrian network in Utrecht, Dom Square area.

---

[2] Source: Dutch Cadastre. See: http://www.kadaster.nl/top10nl/ (January, 2011)

Another important improvement of pedestrian networks compared with the traditional street network, is the standardized set of attributes assigned to its elements. As pedestrian networks represent different objects (pavements, pedestrian crossings and walkways) rather than the traditional ones (street centre-line), its attributes also differ. Therefore, the standardized set of attributes' information assigned to the pedestrian network will, on the one hand, improve its usage results and, on the other hand, increase the number of possible pedestrian-based applications.

Most of pedestrian network's attributes need to be derived from either aerial images analysis or field work (like pavement width, pavement type; pedestrian crossings' traffic signs, ramps, etc.). For this reason, attributes information has not been calculated / collected within this case study.

When no attributes are taken into account, overall travel distances between the traditional street network and the pedestrian network showed similar results. Even though, the shortest paths analysis results differ between them (example illustrated in figure 8). Moreover, the resulting routes from the pedestrian network represent the real paths through the walkable area of the streets. This way, the assumption that pedestrians walk on the correct side of the street is no longer needed.
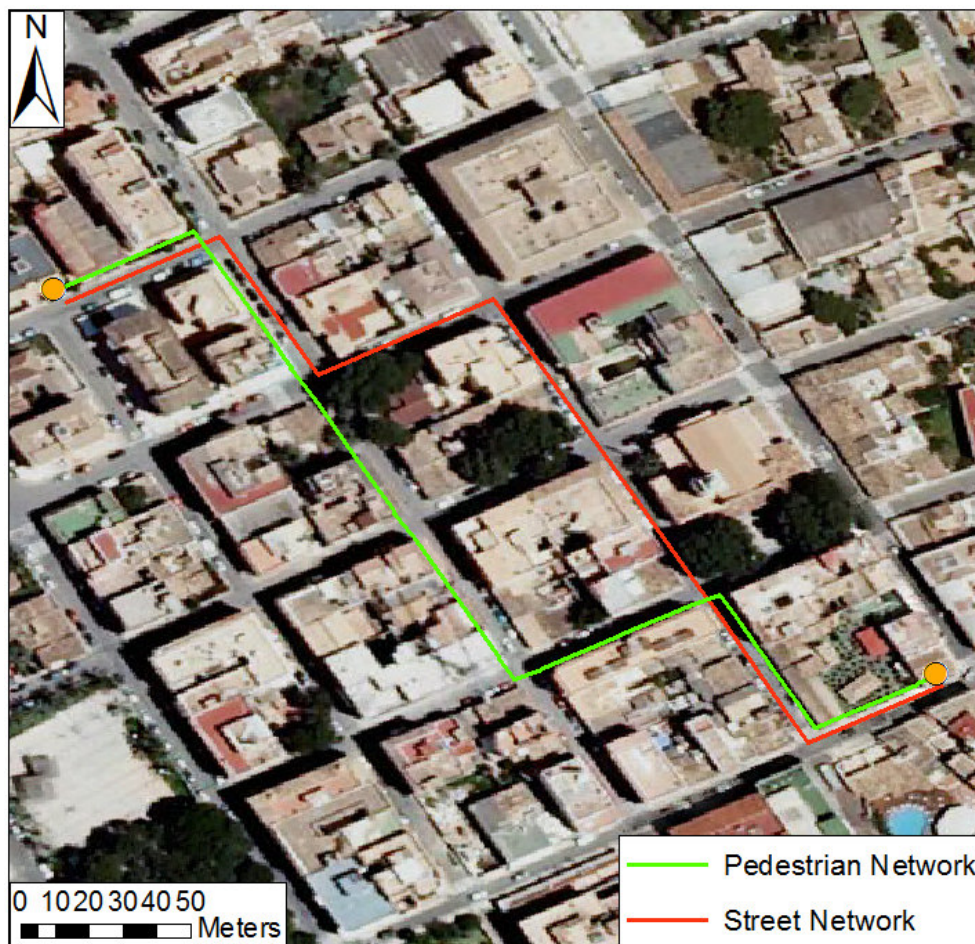

Figure 8: Differences in shortest path analysis in Cala Rajada, Mallorca.

Problems encountered in the model outputs mostly derive from errors already existing in the input. This is one of the most commonly encountered problems when dealing with geo-information. Experts commonly express its effects as: garbage in, garbage out.

The most important errors encountered in the output pedestrian network derived from problems or inconsistencies existing in the input geo-datasets are:

- Pedestrian areas such as squares/parks or walkable traffic islands are not contemplated in the input. Nonetheless, most of them have been derived as intermediate tool result and used to generate the output.
- In some cases streets are not represented by a single line. In these cases an amalgamation process will be needed in the input (as illustrated in figure 9). Dual carriages and roundabouts (over 5m width) are recognized as squares and/or traffic islands and are stored as intermediate model results.
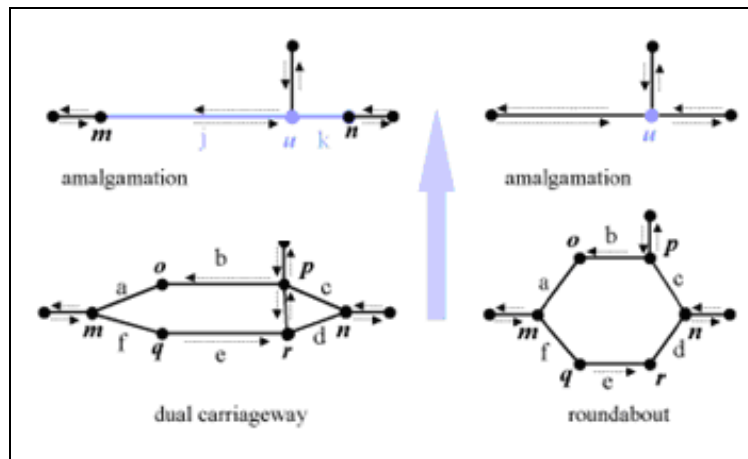

Figure 9: Streets simplification method. Source: Scheider, S. and Schulz, D., 2007

- Missing streets or inappropriate street connections, as shown in the figures below:
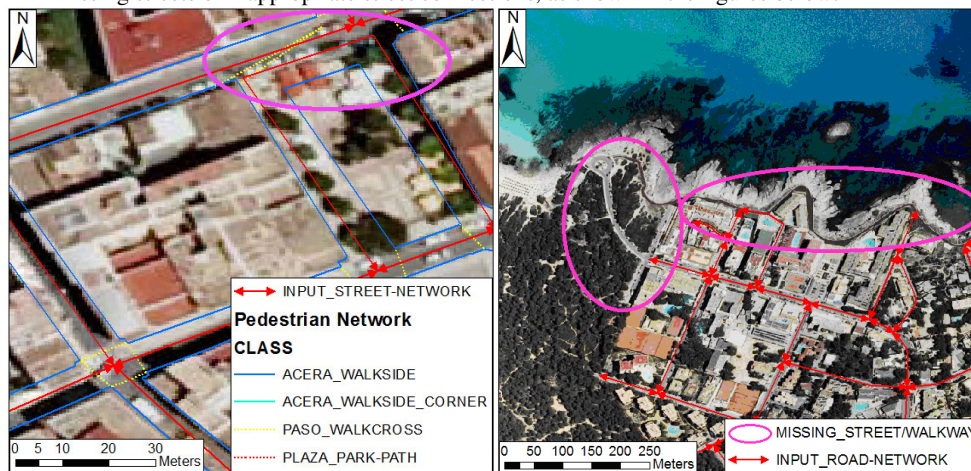

Figure 10: Inappropriate input street connection (left) and
missing streets and walkways (right), in the purple areas.

- Walkways, pedestrian bridges and park paths are mostly not digitized. Even though, they are represented in the output pedestrian network by (parts of) the input street lines crossing squares, parks or traffic islands.
- Street (centre-lines) digitized erroneously on the top of blocks (polygons) without representing a real pass (as illustrated in figure 11). All lines overlapping less than the defined distance (5m by default) are understood as digitizing errors and its effects/errors on the output network rectified.

Possible improvements

Although the proposed methodology resulting in a highly feasible and realistic pedestrian network, several improvements can still be applied, such as:
- Include walkways, pedestrian bridges, park paths or trekking routes not present in the input datasets
- Improvements derived from including input streets attributes information to the output pedestrian network. The implementation of these improvements represent a problem because each source has its own format and set of street attributes, whose quality is often unknown (Scheider, S. and Schulz, D. 2007). Some examples are:

- Derive walkway-streets from the input street map's attributes
- Improve the inter-urban road pavements by assigning different width according to an existing road classification attribute field.
- Remove pavements from high traffic road such as highways or motorways as they mostly are inaccessible to pedestrians
- Informal pedestrian crossings (un-signalized) should be removed from high traffic areas as they may be dangerous and unaccessible
- Collect the standardized set of information of attributes
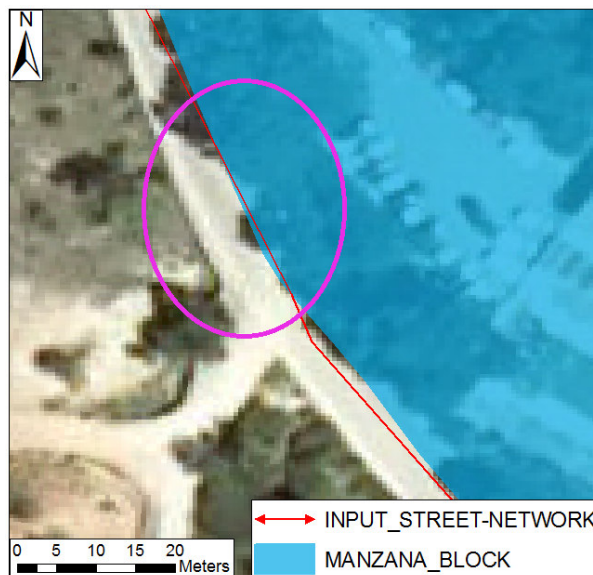
Figure 11: Street network overlapping blocks, in the purple area.

Further research

The traditional street network is commonly used to solve pedestrian mobility issues but its results are shown not to adjust pedestrians' reality. The proposed method opens a new door that promotes research concerning pedestrian-focused attributes related to the objects that make its networks (pavements, signalized/un-signalized pedestrian crossings, walkways, pedestrian bridges, parks paths, etc.).

There is the possibility of uploading the developed three-step tool into a geo-portal to make them available to non-ArcGIS users. The 'free' availability of pedestrian networks would generate the opportunity of developing several applications barely explored or even un-imagined in a wide variety of fields, such as, health, universal mobility, tourism, pedestrian routing, crowd movements in spatio-temporal modelling or planning support systems.

BIBLIOGRAPHY

Balearic Islands Government, 2003. Decree 10/2003 'Del Reglamento de Supresión de Barreras Arquitectónicas'. BOIB, Num. 4706, pp. 132-148

Cerin, E., Leslie, E., Owen, N. and Bauma, A., 2007. 'Applying GIS in Physical Activity Research: Community 'Walkability' and Walking Behaviors'. In Lecture Notes in Geoinformation and Cartography, Part 6, DOI: 10.1007/978-3-540-71318-0_6, pp. 72-89

Cartociudad Project, Official website: http://www.cartociudad.es (December, 2010)

Chin, G. K. V., Van Niel, P. K., Giles-Corti, B. and Knuman, M., 2008. 'Accessibility and connectivity in physical activity studies: The impact of missing pedestrian data'. Preventive medicine, vol.46, iss.1, pp. 41 -45

Clifton K.J., Livi Smith A.D., Rodriguez D., 2007. 'The development and testing of an audit for the pedestrian environment'. Landscape and Urban Planning, vol.80 pp. 95-110.

Dutch Cadastre, Official website: http://www.kadaster.nl/top10nl/ (January, 2011)

Goetzke, F. and Andrade, P. M., 2010. 'Walkability as a Summary Measure in a Spatially Autoregressive Mode Choice Model: An Instrumental Variable Approach'. In Advances in Spatial Science, Part 2, DOI: 10.1007/978-3-642-03326-1_11, pp. 217-229

Handy S., Boarnet M., R. Ewing and R.E. Killingsworth, 2002. 'How the built environment affects physical activity: views from urban planning'. American Journal of Preventive Medicine, vol. 23, pp. 64–73

IMSERSO, 2004. 'Plan Nacional de Accesibilidad 2004-2012'. Labour and Social Affairs Spanish Ministry. Elderly and Social Services Institute, Madrid

Kim, Y. K., Shin, H. W. and Kong, E. M., 2007. 'Establishing a Method to Construct Pedestrian Network in Downtown Area'. Proceedings, 6th International Space Syntax Symposium, Istanbul, sp. 115

L. Frank and P. Engelke, 2001, 'The built environment and human activity patterns: exploring the impacts of urban form on public health'. Journal of Planning Literature, vol. 16, pp. 202–210

Mail and Telegraph State Society [Correos], Official website: http://www.correos.es (December, 2010)

Mohareb, N. I., 2009. 'Street morphology and its effect on pedestrian movement in historical Cairo'. Cognitive Processing, vol. 10, Suppl. 2, DOI 10.1007/s10339-009-0283-x, pp.253–256,

National Geographic Institute (IGN), Official website: http://www.ign.es (December, 2010)

National Statistic Institute [INE], Official website: http://www.ine.es (December, 2010)

Open Street Map, Official website: http://www.openstreetmap.org (December, 2010)

Pérez Ruiz, M. Petrus Bey, J. M, and Ramon Molinas, J., 2008. 'Gestió de l'accessibilitat urbanística i arquitectònica mitjançant tecnologies de la informació geogràfica: Sistema d'Informació Geogràfica de l'Accessibilitat de Mallorca (SIGAM)'. Alimara, Num. 54

Pérez Ruiz, M. Petrus Bey, J. M, and Ramon Molinas, J., 2010. 'Anàlisis de la Accesibilidad Urbanística y Arquitectónica: SIG de Accesibilidad de Mallorca'. XIV Geographic Information Technologies Spanish National Congress (TIG), Sevilla

Scheider, S. and Schulz, D., 2007. 'Specifying Essential Features of Street Networks'. In Spatial Information Theory 8th International Conference, Edit. COSIT, LNCS 4736, pp. 169–185

Smith, K. R., Brown, B. B., Yamada, I., Kowaleski-Jones, L., Zick, C. D. and Fan, J. X., 2008. 'Walkability and Body Mass Index: Density, Design, and New Diversity Measures'. American Journal of Preventive Medicine, vol. 35, iss. 3, pp. 237-244

Spanish Cadastre (DGC), Official website: http://www.catastro.meh.es (December, 2010)

Yari, I. E. and Igi, S., 2007. 'Universal Designed Mobility Support: Geographical Information Systems for All Pedestrians'. Journal of the National Institute of Information and Communication Technology, vol. 54, iss. 3, pp. 135-144